International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN(P): 2249-6890; ISSN(E): 2249-8001
Vol. 4, Issue 4, Aug 2014, 1-14

EFFECT OF V NOTCH SHAPE ON FATIGUE LIFE IN STEEL BEAM MADE OF MILD STEEL AISI 1020

QASIM BADER[1]& EMAD K. NJIM[2]

Lecturer at College of Engineering, University of Babylon, Hilla, Iraq

MScStudent, Applied Mechanics,College of Engineering, University of Babylon, Hilla, Iraq

ABSTRACT

The present work encompasses Effect of notches with various notch geometries and dimensions on fatigue life in steel beam made of Mild Steel AISI 1020 which has a wide application in industry. Fatigue life of notched specimens is calculated using the fatigue life obtained from the experiments for smooth specimens and by use Numerical method (FEA).The fatigue experiments were carried out at room temperature, applying a fully reversed cyclic load with thefrequency of 50Hz and mean stress equal to zero (R= -1), on a cantilever rotating-bending fatigue testing machine.The stress ratio was kept constant throughout the experiment. Different instruments have been used in this investigation like Chemical composition analyzer type (Spectromax), Tensile universal testing Machine type (WDW-100E), Hardness Tester type (HSV- 1000), Fatigue testing machine model Gunt WP 140, Optical Light Microscope (OLM) and Scanning Electron Microscope (SEM) were employed to examine the fracture features. The results show that there isacceptable error between experimental and numerical works.

KEYWORDS: V Notch, Stress approach, Mechanical Tests, Fatigue life, Stress Concentration Factor, FEA

INTRODUCTION

It has been estimated that 90 % of all service failures of metal parts are caused by fatigue. Fatigue is the process of progressive localized permanent structural changes occurring in a material subjected to conditions that produce fluctuating stresses at some point or points and that may culminate in cracks or complete fracture after a sufficient number offluctuations [1].A fatigue failure is one that occurs under cyclic or alternating stress of an amplitude that would not cause failure if applied only once. Fatigue is by far the most common cause of mechanical failure in engineering components; the prevention of fatigue failure is a major preoccupation of designers in many industries, such as power generation and transport [2].

The term "notch" in a broad sense is used to refer to any discontinuity in shape or non- uniformity in material such as the V-shape threads on nut-bolt connections, the square-shape key washer's grooves on shafts, scratches, nonmetallic inclusions and corners, fillets and geometry discontinuities, The failure usually originates in the formation of a crack at a localized point on the notches. Presentation of notches in.Presentation of notches in structural components causes stress intensification in the vicinity of the notch tip [3]. A. Fatemi,Z. Zeng and A. Plaseied [4], investigated in their study addressed "Fatigue behavior and life predictions of notched specimens made of QT and forged microalloyed steels" Fatigue behavior of notched specimens using circumferentially notched round bar and double-notched flat plate geometries, each with different stress concentration factors. Guy Pluvinage [5], described in his research "Notch Effects in Fatigue and Fracture", the notch effect in fracture is characterized by the fact the critical gross which acts on the remaining

alignment are under notch tip, the notch effect in fracture is sensitive to structure geometry and the Wohler curve for the notched specimen is below the smooth specimen curve. Reference [6], explained "The Notch Effect on the Fatigue strength of 51CrV4Mo spring steel", standardized and technological testing of the fatigue strength of spring steels is a complex and time-consuming, and therefore expensive, task. The determination of Wohler's (S-N) curves using a resonant pulsator is relatively fast and simple.

Celalettin Karaagac [7], presented a thesis that attributes the failure (fracture) of an agitator shaft with a circumferential notch was selected as investigation topic. However, this study is intended for introducing fracture mechanics from an application viewpoint. It essentially focuses on both stress and fatigue analyses.

Nasim Daemi, Gholam Hossein Majzoobi [8], have been developed experimental and theoretical life on notched specimens under bending, fatigue life of notched specimens with various notch geometries and dimensions was investigated by experiment and Manson-Caffin analytical method.

An experimental investigation was achieved by N.A.Alang, N.A.Razak &A.K.Miskam [9], they have been used cantilever rotating-bending fatigue testing machine to study the effects of surface roughness on the fatigue life of carbon steel.

Reference [11], shows Failure cycles of notched round specimens under strain controlled cyclic loading by using strain life relations obtained from experiment for plain fatigue round specimens. The maximum strain is computed by appropriate Finite element analysis using the FE software ABAQUS. They obtained that the total strain life curve generated from fatigue test of round specimen can also be used for the prediction of life for notched specimens based on actual strain developed at notch tip, the results shows that in most of the cases the predicted life is found to be less compared to experimental values for all the types of notched specimens.

EXPERIMENTAL WORK

The experimental work included assessment of fatigue life specifications by using stress life approach for Mild steel AISI 1020 supplied from the local market with and without notches and the effect of angle orientation, depth of notch on the fatigue limit. The experimental procedure consist of four parts, the first one deals with the selection of materials used and the specimens preparation, the second part deals with different mechanical tests, the third includes details of fatigue test and finally the details of Microscopic inspection as shown in Fig. 1. A brief description for the different equipment used in this study had mentioned. Fig. 2 states clearly specimens distribution have been used.

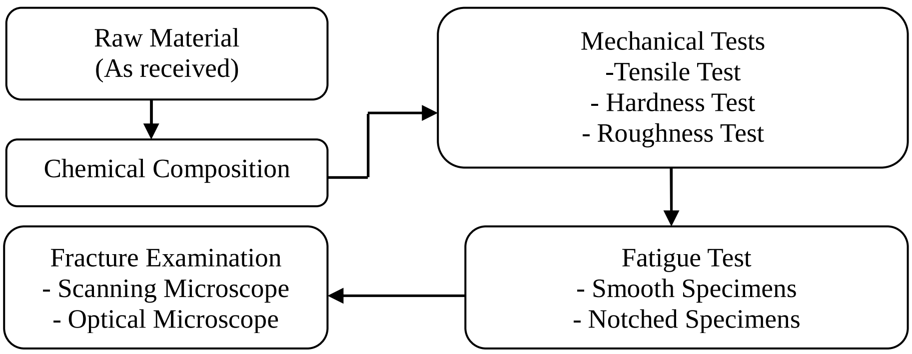


Figure 1: Stages of Experimental work

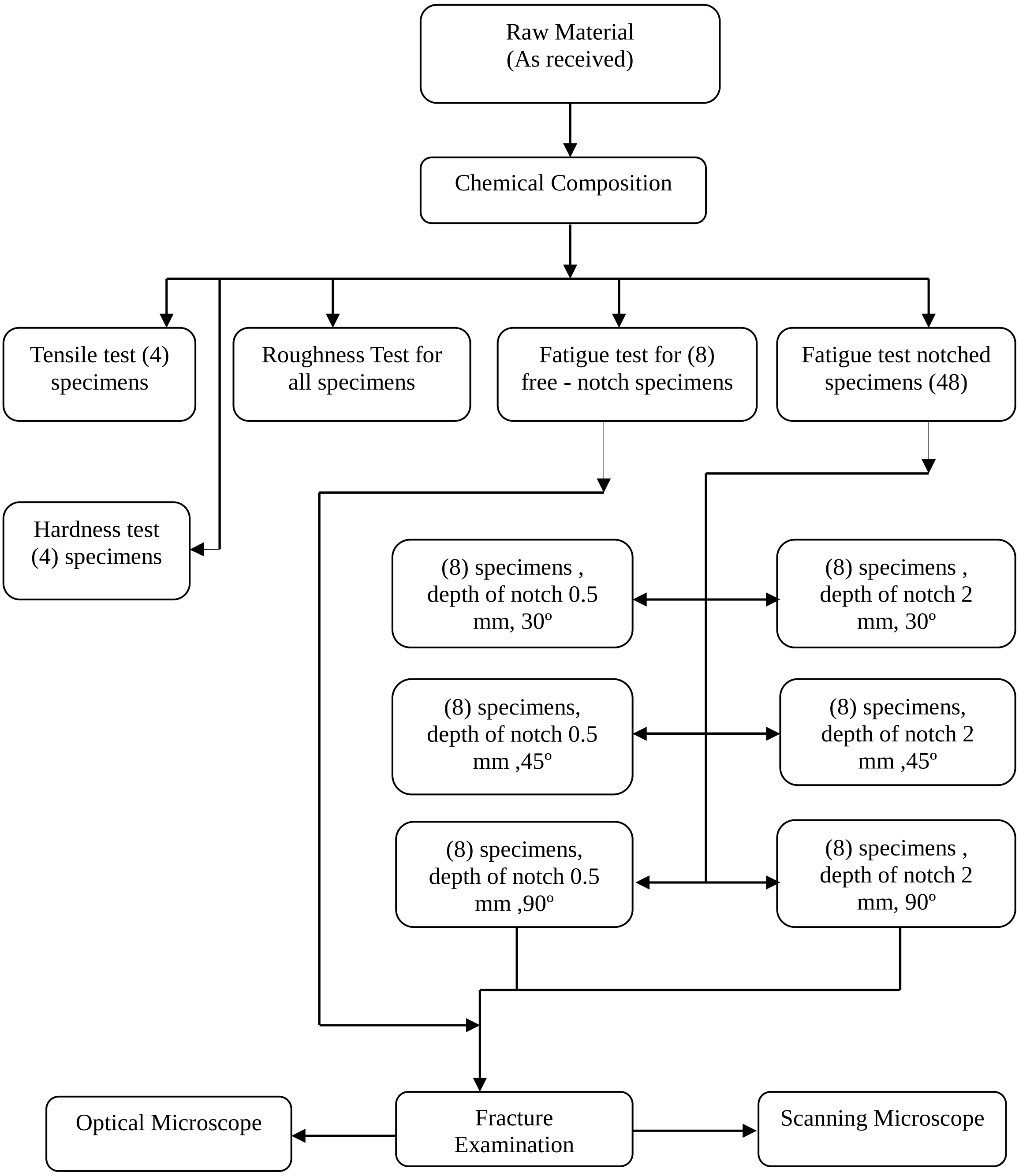


Figure 2: Specimens Distribution

Table 1: Chemical Composition of Mild Steel AISI 1020 (wt%)

Element	C	Si	Mn	P	S%	Fe
Measured	0.208	0.27	0.603	0.012	0.021	Bal.

Material Selection

In this work, Mild steel alloy AISI 1020 treated commercially, was used in this investigation, This type of steel alloy has a wide application in industry. The chemical composition test of the alloy was done by use the device Spectrometer type (ARC. MET 8000). The purpose of analyzing the chemical composition of the steel samples is to enable it's classification to be made, the results was within the specification limits and as shown in Table 1.

MECHANICAL TESTS

Tensile Test

The tensile test is a standard test which was conducted using the microcomputer controlled electronic universaltesting machine type (WDW-100E - 100KN) as shown in Fig. 3, The load was applied at a constant rate of(2 mm/min) during all tests until failure of specimen occurred. The specifications of the tensile test have been restrictedaccording to the American Society for Testing and Materials specifications (ASTM) [12], at room temperature; the tensile specimen geometry and dimensions was prepared according to standards of ASTM. A 370 and as shown in Fig. 4. Average value of four readings for the test have been taken to satisfy an additional accuracy; the results are given in table 2.

Table 2: Tensile Test Results

Tensile Strength σu (MPa)	Yield Strength σy (MPa)	Elongation [%]	Modula's of Elasticity (Gpa)
470	350	26	209

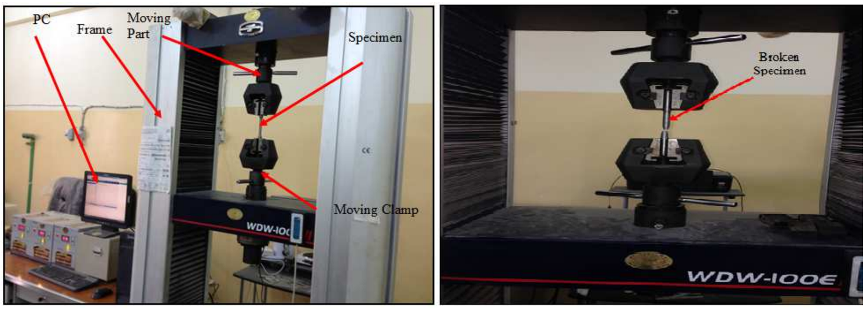


Figure 3: Tensile Testing Machine

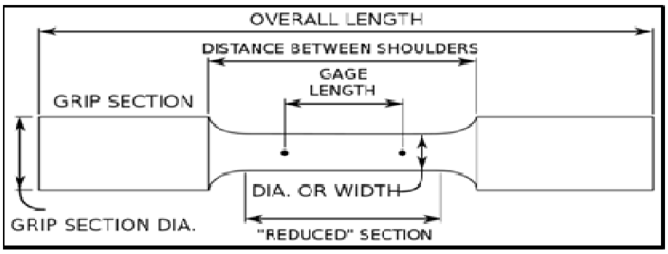


Figure 4: Tensile test specimen according to specification A 370

Hardness Test

Hardness is the property of a material that enables it to resist plastic deformation, usually by penetration.However, the term hardness may also refer to resistance to bending, scratching, abrasion or cutting; hardness test of a metal is generally performed to know is resistance against indentation and abrasion. Though there are two tests have been done in thisinvestigation Brinell's and Vickers's Hardness test. The average value of four readings was recorded the results are shown in Table 3.

Table 3: Hardness Test Results

Brinell Hardness (HB)	135
Vickers Hardness (HV)	142

Roughness Inspection

Surface roughness and surface integrity resulting from manufacturing processes are both important considerations in fatigue design. Fatigue damage on the surface of a component typically develops due to the surface integrity resulting from manufacturing, and the presence of stress concentrations originating from the surface topography. The specimens were first polished with different wet oxide aluminum papers by different degrees,then followed by polishing with a string cloth soaked in alumina. Once the manufacturingprocess of the specimens was done the surface roughness was measuredby using a portable Surface roughness tester type(SADT) as shown in figure 5 and in order to reduce human errors during the measurement, the reading was taken for three times at different points and for all notched and smooth specimen. Then, the average and total surface roughness, R_a and R_t are calculated and summarized in Table 4.

Table 4: Values of Surface Roughness

R_a [μm]	R_t [μm] max
1.75	3.25

Figure 5: Portable Surface Roughness Tester

FATIGUE TEST

Fatigue Test Specimens

Fatigue specimens were machined in suitable dimensions to satisfy the requirement of the machine test that suited cylindrical specimens. Two types of fatigue specimens smooth and notched were prepared according to machinespecifications. All the smooth and notched cylindrical fatigue specimens were machined from AISI 1020 carbon steel alloy by using a programmable CNC machine adopting standard manufacturing procedure and circumferential V notch of angle of (300, 450 and 900) to a depth of notch was (0.5 and 2) mm respectively[13]with a notch radius as small as possible (<0.075mm) [14]and was introduced at the portion of maximum bending. A Grinding process has been done for the cylindrical fatigue specimens by use emery papers from Silicon Carbide with different ASTM grades (#600,800,1000,1200,2000),then polishing process done by use Alumina solution with cloth, and the residual stresses were minimized by the heating process to (350) centigrade for one hour inside furnace and then cooling by air. The minimum diameter of each specimen was measured at positions around the circumference on a toolmaker's microscope at (30) magnification. Specimens having a variation of more than (0.05 mm) in diameter were discarded. The fillet radii of the stress concentration specimens were checked at the same time that the diameter was measured. The geometry of these and a schematic view specimen are given in Figure 6.

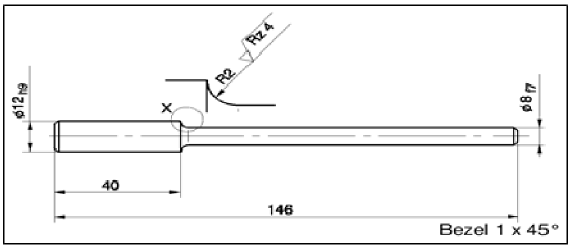


Figure 6: Schematic Diagram for Fatigue Test Specimens (mm)

- **Rotating Bending Machine**

The fatigue behavior of different materials can be determined from laboratory tests.The type of fatigue testing machine is revolving fatigue testing machine type WP 140, (a single cantilever rotating bending model) with a constant amplitude (fully reversed bending). A rotating sampleis clamped which on one side is loaded with a concentrated force with a maximum capacity of (0.3 KN) with constant frequency of (50Hz). A sinusoidal cyclic load with a stress ratio R = -1 (minimum load/maximum load) was applied throughout the experiment. As a result, an alternating bending stress is created in the cylindrical sample following a certain number of load cycles, the sample will rupture as a result of material fatigue. Tests were carried out at room temperature (20 -24 °C), and environmental humidity comprised between (54-58%). The machining process for all specimens was maintained as constant as possible in order to avoid significant variation in the surface polish. High temperature is expected at the narrow section when the specimen is tested under loading close to elastic limit. A cooling system with cool air was employed in the lab building to maintain the temperature in this zone below 100 °C in order to restrict the highest testing temperature. Under this condition, it is assumed that there is no variation in the specimen microstructure. The experiment was conducted by repeating so many similar procedure tests for all specimens. Bending moment values were used to determine the alternating bending stress, which can be determined directly from equation (3).

The bending moment is calculated with the load and the lever arm as follows:

$$M_b = F \ x \ a \quad (1)$$

By using the section modulus of the sampleIt is possible to calculate the alternating stress amplitude.

$$W_b = \frac{\pi d^3}{32} \quad (2)$$

$$\sigma_a = \frac{M_b}{W_b} = \frac{32a}{\pi d^3} F \quad (3)$$

$$= 2F\,(MPa) \quad (4)$$

Where;

σ_a**:** is the maximum alternating stress (MPa)

F**:** Applied Force (N)

a**:** bending arm = 106 ±0.1 mm

d**:** diameter of the specimen = 8±0.1 mm

M_b = bending moment (N.mm)

W_b= Moment of inertia (for hallow cylinder)

A series of tests was commenced by acting a specimen to the stress cycling, and the number of cycles to failure was counted. This procedure was repeated on other specimens at progressively decreasing stress amplitudes. Data were plotted as stress $\sigma_a$versus the logarithm of the number N of cycles to failure for each of the specimens. It is important to know that each S-N curve obtained by this study has at least 8 specimens in both cases with and without notches-N curves are plotted by using software of Fatigue instrument present in PC which is connected directly to instrument as shown in figure 7.

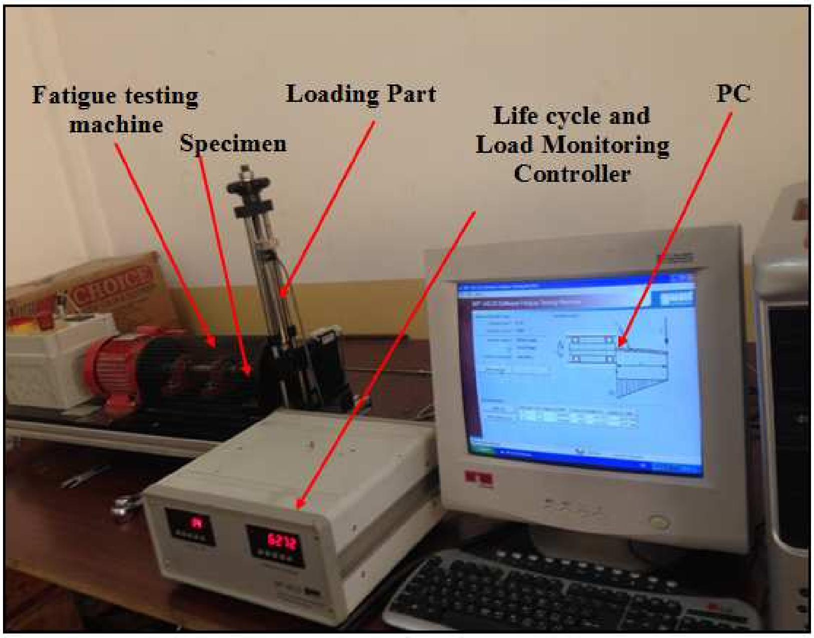
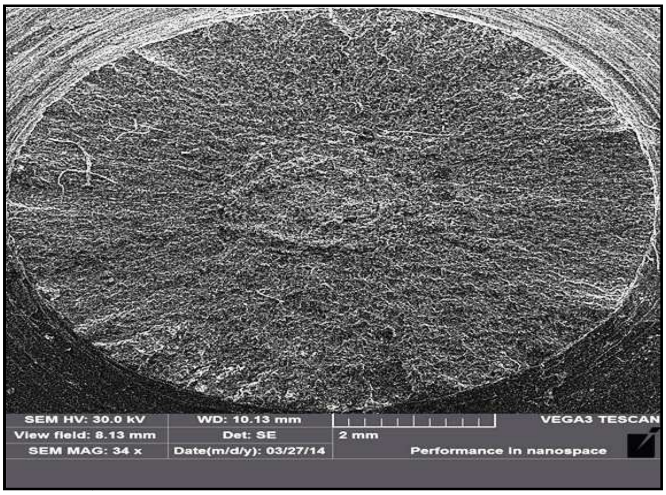


Figure 7: Fatigue Testing Machine WP 140

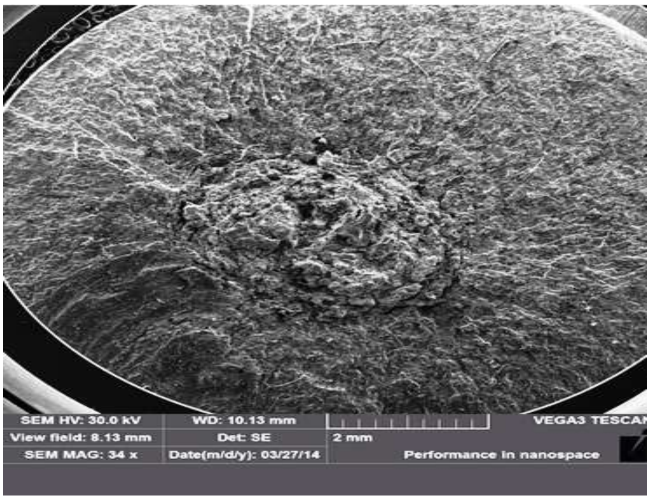
Examination Fracture Fatigue

The process of achieve test fracture for the different fatigue specimens has been done to check the nature of fracture. Fracture surfaces of failed specimens have been analyzed using Optical Microscope (OM) and Scanning Electron Microscope Zeiss type (EVO 50).Samples for microstructure examination were ground using different grades of wet silicon carbide papers (260, 500, 800, 1200 and 2000, then the samples were polished using two type of alumina (0.5 micron and 0.3 micron). Distilled water and alcohol were used to clean the samples in succession.

Etching was carried out with naital (2 % HNO3) in alcohol followed by washing them with water and alcohol. Figure 8 illustrates the photo digital system.



(a)



(b)

Figure 8: Fracture Surface of a Specimen AISI 1020, (a) Without Notches,(b) With Notches

NUMERICAL INVESTIGATION

It is estimated that 50-90% of structural failure is due to fatigue, thus there is a need for quality fatigue design tools. However, the availability of commercial fatigue tools is limited while the ones that are available are usually quite expensive and difficult to use in the hands of a designer. It is hoped that these designers, given a proper library of fatigue tools, could quickly and accurately conduct a fatigue analysis suited to their needs in a friendly and well structured environment. The finite element method (FEM) is now widely used in a variety of fields in engineering and science. Notched fatigue specimens with different notch angles and depths of notch are modeled and FE simulated results are generated for fatigue loading at different stress amplitude by using ANSYS program Version 11. The mechanical properties and Stress life data obtained by experiments. The element meshes were generated, boundary condition corresponding to maximum loading condition was given and. Stress analysis through ANSYS also show that maximum value of stress occurs at the vicinity of change in cross section of the shaft where a V notch with different angle orientation 30,45 and 90 degree with different notch depth 0.5 and 2 mm are present. Figures 9 &10 explain model with boundary conditions and maximum principle stresses generated in the model.

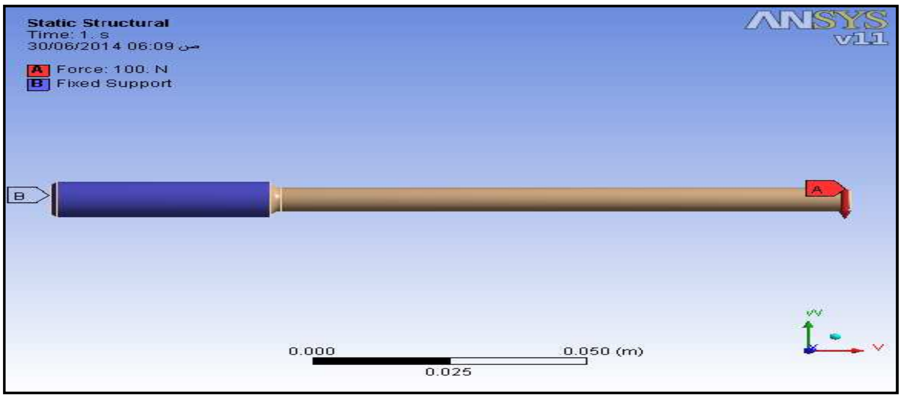


Figure 9: Model for Free-Notch specimen

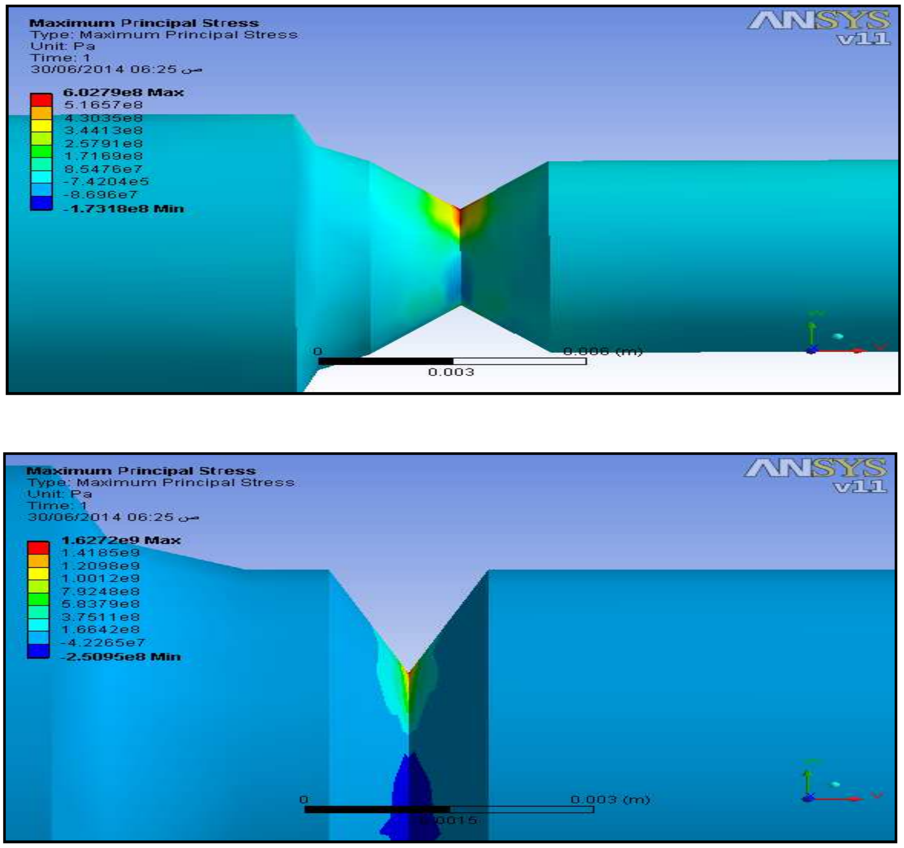


Figure 10: Comparison of Principle Stresses Generated in Model for 90 and 45 degree

RESULTS

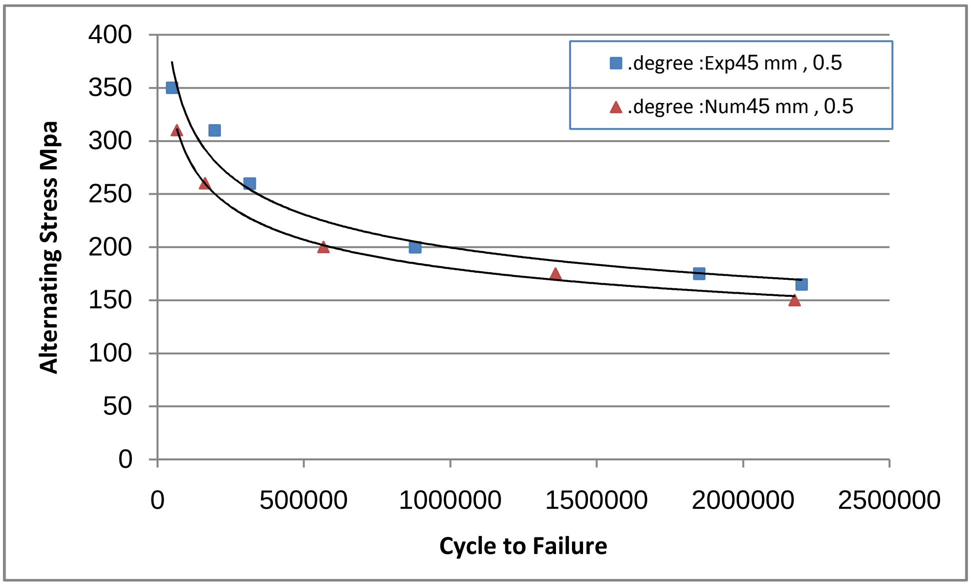
In this work it is trailed to predict the fatigue life of notched fatigue specimen under effect of cyclic loading using stress life data of smooth fatigue specimen (without notch) on the basis of maximum stress developed obtained from finite element simulated results of notched specimen under stress controlled cyclic loading. The accuracy of prediction in this method depends on the correctness of the material total stress-life curve generated from experimental results of HCF data of cylindrical specimens and the accuracy of simulated value of maximum stress of notched specimens. The Mechanical

properties of the material have been found by using many adequate tests for many samples to minimize errors as soon as possible.

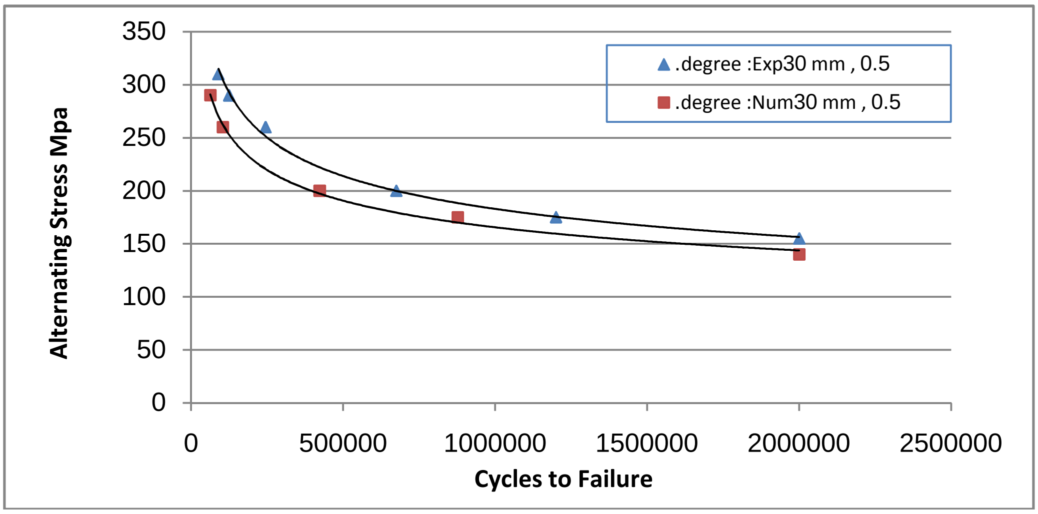
The accuracy of the predicted life by FE simulation depends on the selection of appropriate material model and the accuracy of the value of the material parameters used. The predicted results fairly match with the experimental results. It is observed that the life prediction FE simulation is acceptable for different stress amplitudes and also at different no of cycles. The maximum error between two methods found 8 %. The common stress life curve generated fromspecimens of several notch angles gives a better prediction, which is apparent from the Figures 11, 12 &13.Stressconcentration factor was obtained using finite element method and.The results are given in table 5, for more details of the procedure for stress concentration determination see [15].

Table 5: Values of Stress Concentration, Fatigue and Notch Sensitivity Factors

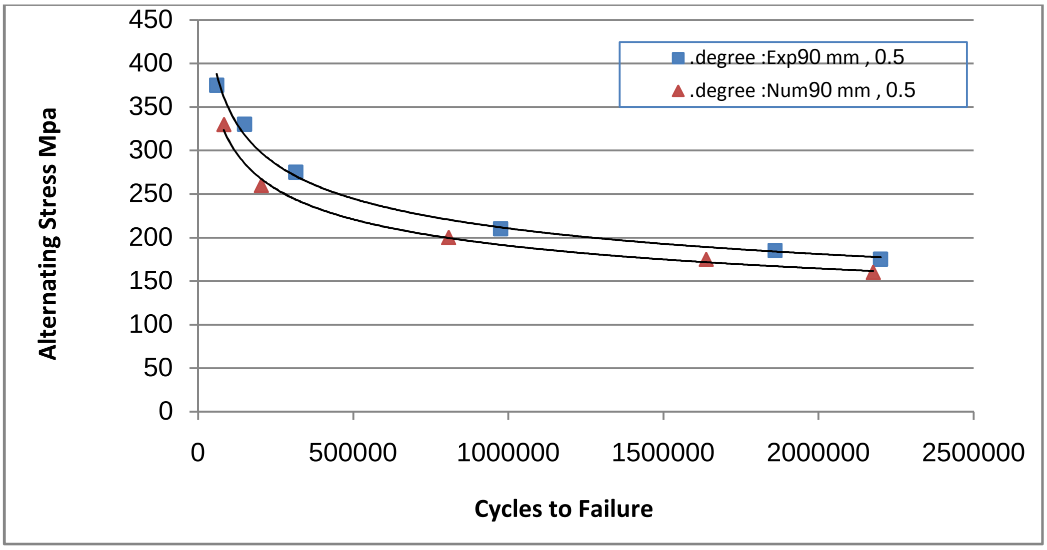
α (Degree)	h (mm)	r (mm)	K_t	q	K_f
30	0.5	0.07	4.28	0.2682	1.88
45	0.5	0.07	4.15	0.2698	1.85
90	0.5	0.07	3.47	0.2672	1.66
30	2	0.07	3.95	0.2678	1.79
45	2	0.07	3.83	0.2685	1.76
90	2	0.07	3.23	0.2690	1.6



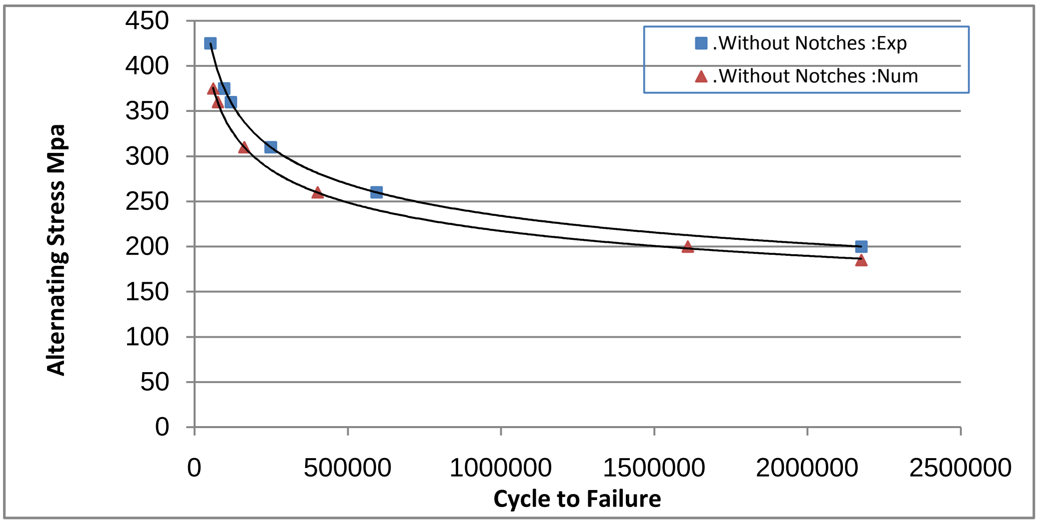
(a)



(b)



(c)



(d)

Figure 11: A Comparison between the Experimental Calculated Fatigue Life for V-Shape Notch: (a) 45^0, (b) 30^0, (c) 90^0, (d) Without Notches

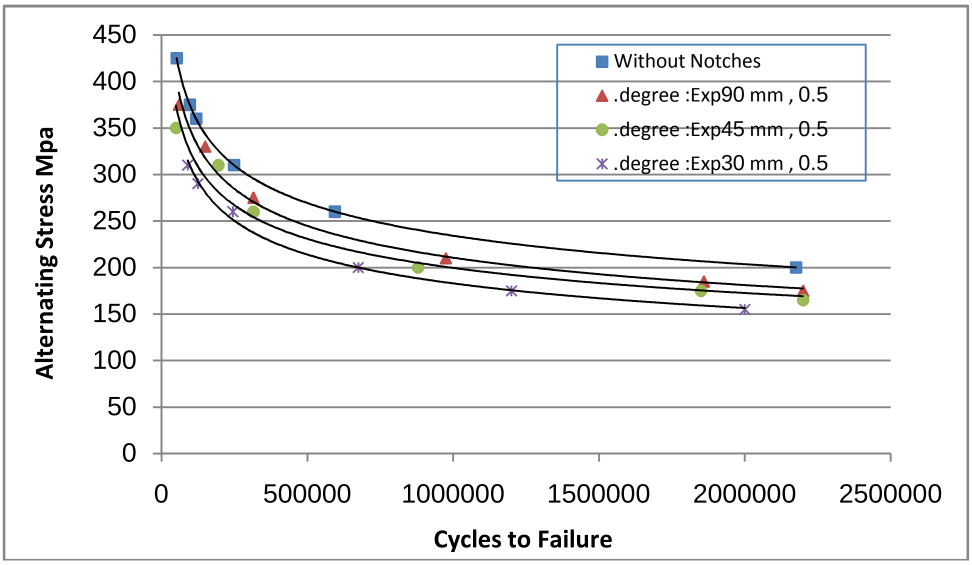


Figure 12: Experimental S-N Curve for V Notched Specimens

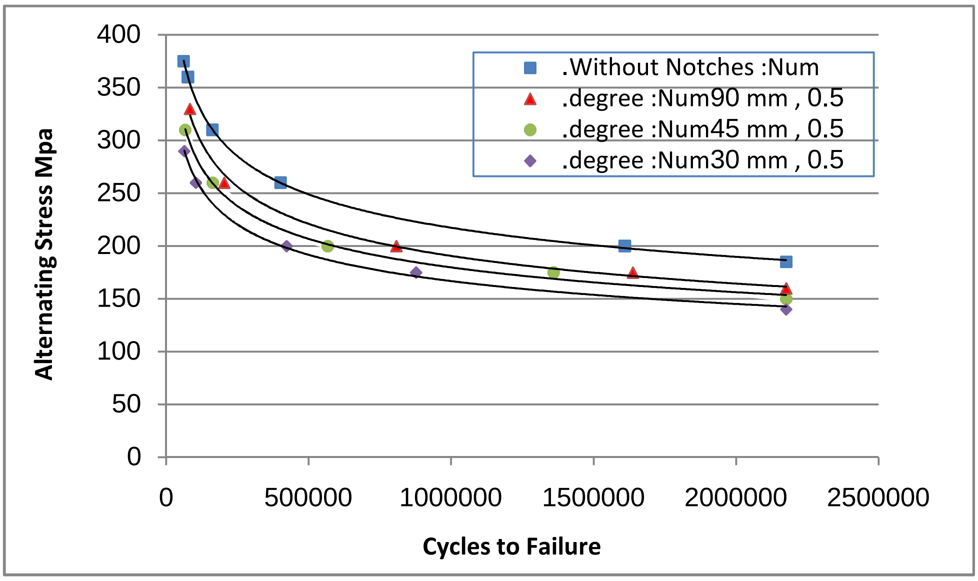


Figure 13: Numerical S-N Curve for V Notched Specimens

CONCLUSIONS

In this work, bending fatigue life of notched specimens with V notch geometry of various angle orientation and notch depth was investigated by experiment and FEA method. The mathematical form of fatigue life equation of the specimens, were obtained by experiment and by use FEA.

The Stress Concentration factor for the Geometry used in this work was calculated analytically and numerically by use FEM. The results indicate the FEA method is applicable to the experiments. The final conclusion can be made from the results obtained that the S-N Curve generated from fatigue test of round specimen can also be used for the prediction of life for notched specimens based on actual stress developed at notch tip. From the results it is also observed that in most of the cases the predicted life is found to be less compared to experimental values for all the types of notched specimens. This

may be due to the fact that the life has been predicted based on maximum stress in notched section[11].The maximum value of stress occurs at the vicinity of change in cross section of the specimen where a relief groove is present.Failure originated as the applied load exceeds the fracture strength of the material.Fatigue limit value has strong relation with mechanical properties of metals, on the other hand it is concluded that for fatigue life equation represented by Basquin's form :

$$\sigma_a = aN^b$$

The coefficients a represent Stress-Life curve intercept and coefficient b is the fatigue strength exponent (Stress-Life curve slope). These coefficients after evaluated by linearizing the power law in logarithmic, it is found that the increasing of tensile stress value affects the change value of those coefficients based on certain factor. The value of this factor needs more experiments to be conducted. This remains to be done in our next investigations.

ACKNOWLEDGEMENTS

This work was partially supported by the Laboratory staff of Kufa University, College of Engineering, Mechanical Department. Thanks to Mr. Hayder Zaini for the experimental assistance.

REFERENCES

1. Juli A. Bannantine, Jess J. Comer, James, L. Handrok, *"Fundamentals of Metal Fatigue Analysis"*, prentice hall, Englewood Cliffs, New Jersey 07632.
2. Yung-Lilee, Jwo pan, *"Fatigue Testing and Analysis"*, Elsevier printer, 2002.
3. Ralph I. Stephens, Ali Fatemi, *"Metal Fatigue in Engineering"*, Second Edition,Mc Graw Hill, 2001.
4. A. Fatemi,, Z. Zeng, A. Plaseied,*" Fatigue behavior and life predictions of notched specimens made of QT and forged microalloyed steels"*, International Journal of Fatigue 26 (2004) 663–672.
5. Guy Pluvinage and Marenglen Gjonaj, *"Notch Effects in Fatigue and Fracture "*, NATO Advanced Research, Kluwer Academic Publishers, 2001.
6. Borivoj Sustarsic, Bojan Sencic & Philippe Jodin,*"The Notch Effect on the Fatigue strength of 51CrV4Mo spring steel"*, Original scientific article, ISSN 1580-2949, MTAEC9, 41(1)29(2007).
7. Celalettin Karaagac,*"failure (fracture) of an agitator shaft with a circumferential notch"*,2011.
8. Nasim Daemi, Gholam Hossein Majzoobi *"Experimental and Theoretical Investigation on Notched Specimens Life Under Bending Loading"*,International Journal of Mechanical and Materials Engineering 2011.
9. N.A.Alang1, N.A.Razak & A.K.Miskam, *"Effect of Surface Roughness on Fatigue Life of Notched Carbon Steel "*,International Journal of Engineering & Technology IJET-IJENS Vol.: 11 No: 01, 2011.
10. M. M. Megahed, A. M. Eleiche, N. M. Abdullah, *"Low-cycle fatigue in rotating cantilever under bending III: Experimental investigation on notched specimens"*, Int. J. Fatigue, 2005, pp. 271-280.
11. Bikash Joadder, Jagabandhu Shit, Sanjib Acharyya,*" Fatigue Failure of Notched Specimen-A Strain-LifeApproach"*,Materials Sciences and Applications, 2011.

12. Annual book of ASTM Standard Section 2, *"Standards Test Methods and definition for Mechanical Testing of SteelProducts"*, designation A 370-07, 2007.
13. Y.Verreman1, H.Guo, *"Short cracks at notches and fatigue life prediction under mode I and mode III loadings"*, Nordam Group, Tulsa, OK, USA.
14. Atzori, B., Lazzarin, P. and Meneghetti, G., *"A Unified Treatment of the Mode I Fatigue Limit of Components Containing Notches or Defects"*, Int. J. Fracture, 133, 61-87 (2005).
15. G.H. Majzoobi, N. Daemi, *"The study of notch geometry on fatigue life using notch sensitivity factor"*,Transaction of the Indian Institute of Metals Journal. vol. 63, 2010, pp.547-55.